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BRITISH COLUMBIA

Impacts of hoe-forwarding on site productivity

by Mary-Jane Douglas[1] and Paul J. Courtin

1.0 INTRODUCTION

Concern over the impacts of ground-based harvesting systems on forest soils and site productivity initially led to the development of site disturbance guidelines by the Vancouver Forest Region in the late 1980's and early 1990's. Depending upon soil texture, forest floor depth, and moisture content at the time of harvest, ground-based harvesting systems, in particular rubber-tired skidders, can compact and rut soils (Miller and Sirois 1986, Corns 1988). Compaction and rutting may affect subsequent tree survival and growth as a result of decreased rooting volume, soil aeration, and soil water permeability. Research has shown these impacts may persist for several decades (Hatchell et al. 1970, Butt 1987, Miller et al. 1996).

Hoe-forwarding ("hoe-chucking") was introduced in the late 1980's to gently sloping terrain in coastal British Columbia to reduce overall logging costs while avoiding the serious site impacts associated with some earlier ground-based logging methods. The hoe-forwarder is a modified hydraulic log loader with lengthened boom and stick for longer reach, higher and wider undercarriage for debris and stump clearance, wider tracks for increased flotation, and larger fuel capacity. It forwards logs by lifting them clear of the ground and swinging them towards the road for loading. Ideally, as the hoe travels across a logged area, it makes one pass to forward the wood, but invariably there are multi-pass trails for either access or machine servicing. Site impacts were expected to be less than those of skidders, even with several machine passes and particularly with the use of puncheon (logs and other debris placed under the machine to reduce soil disturbance and ground pressure impact).

The main objective of this study was to determine the short and long-term effects of the hoe-forwarding harvesting method on seedling survival, growth and performance at varying levels of machine disturbance. This report focuses on results from a study area at Stranby River, near Holberg, northern Vancouver Island. A more complete report of these results is available in Douglas (2001). Results from a second study area at Surprise Creek, near Woss, central Vancouver Island, will be reported in future.

2.0 STUDY AREA

The study area at Stranby River is in the CWHvh1 biogeoclimatic variant and the site is representative of the 01 site series (Green and Klinka 1994). The site was selected because of its fairly uniform mineral soils on a relatively flat fluvial terrace. The soils are silt loam Orthic Humo-Ferric Podzols, imperfectly to moderately well drained, with 25-35% pebble-sized coarse fragments in the surface 60 cm of soil. The texture of the mineral soil changes to a loamy sand texture below 60 cm, with larger cobble-sized coarse fragments ranging between 50 and 60%. The forest floor depth averaged 43 cm at the time of treatment.

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Plate 1. John Deere 992D hoe-forwarding machine used in the trial. A green western hemlock log was used to simulate the disturbance of logging.

In 1989, a stand of western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*) had been logged at the study area. The major understory species were salal (*Gaultheria shallon*), oval-leaved blueberry (*Vaccinium ovalifolium*), Alaskan blueberry (*Vaccinium alaskaense*), and salmonberry (*Rubus spectabilis*).

3.0 EXPERIMENTAL LAYOUT AND SAMPLING

Three treatment blocks were established in an area that featured two former stand types with varying proportions and age-class distributions of western hemlock and amabilis fir, and with varying levels of understory vegetation, slash loading, and forest floor depth. Block 2 was originally a mature, essentially even-aged stand that developed following a major windstorm in 1906. This block was representative of the HA phase described by Lewis (1982). Blocks 1 and 3 had consisted of older western hemlock and amabilis fir stands that very likely originated from a much earlier windfall event. These stands were sufficiently old to be 'deteriorating' or transitioning from the HA towards the CH phase (Lewis 1982).

Four 50m treatment lines were laid out in areas undisturbed by the previous logging in each of these three treatment blocks. Each treatment line was randomly assigned a treatment of either no-pass (control), one pass, two passes, or four passes with the hoe-forwarding machine (for a total of 12 lines on the study area). Hoe-forwarding was simulated during the treatment by swinging an 11m western hemlock log, weighing 8,000 kg, five to seven times every 5m along each of the trails (Plate 1). This ensured that the treatments were relatively consistent and well documented. The machine had a mass of 57,900 kg supported on a track area of 8.64 m^2, yielding a nominal ground pressure

Plate 2. Very deep compression of organic mound on Block 3 after four passes by the hoe-forwarding machine.

of 65.8 kPa (9.54 psi). Protective puncheon was used under the machine at all times and the treatments were completed at the end of August 1991.

Soil properties were assessed prior to and immediately following treatment. These properties included soil texture, soil moisture content at the time of trafficking, depth of forest floor, and mineral soil bulk density (collected only from the undisturbed control and from the four-pass track treatment, in order to determine the "worst case scenario").

Soil disturbance was also assessed following treatment. Disturbance levels were conducted for the most westerly track of each 50m tracked strip using point samples at 1m intervals. This methodology was similar to Curran and Thompson (1991) but predates that currently used for ground disturbance surveys under the Forest Practices Code (Province of British Columbia 1997). Disturbances tallied included depth of compression of the forest floor, decayed wood or mineral soil; impressions into these materials by puncheon; and deposits of either organic materials or puncheon that had been left in place. Various combinations of these disturbance types were also noted. Depth of disturbance was tallied using the following classes: shallow = <5 cm; deep = 5-25 cm; and very deep = > 25 cm.

Twenty-five western hemlock seedlings were assigned for planting in one of the tracks, in between the tracks, and on one of the flanks (sub-treatments) of each of the three treatments. A single row of 25 trees was assigned to the no-pass (control) treatment, for a target of 750 seedlings across the trial. Planting constraints in the spring of 1992 reduced this to 737 seedlings. Mortality has since reduced the number to 587 trees.

Seedling height, root collar diameter, survival, and condition were assessed at the end of the first, third, fifth and ninth growing seasons. Five condition classes were used:

1. excellent – seedling has good form and healthy green colour;
2. good – seedling may be slightly chlorotic but generally looks healthy, or seedling is green and healthy but has double or multiple leaders;
3. fair – seedling is quite chlorotic, small in size, may have double/multiple leaders and generally fair to poor health;
4. poor – seedling is stunted, losing needles, chlorotic, may have multiple leaders, possibly moribund;
5. dead – seedling has died between two measurement periods.

Foliar analysis was carried out at the end of the fifth growing season to determine the seedling foliar content of N, P, K, Ca, Mg, Al, S, Cu, Zn, Fe, Mn, B and SO_4-S. Differences in foliar levels were compared between treatments to determine treatment impacts on nutrient uptake. In addition, the foliar levels were also compared with critical levels suggested by Ballard and Carter (1986), and more recently by Carter (1992).

4.0 RESULTS AND DISCUSSION

4.1 SOIL MOISTURE CONTENT AND BULK DENSITY

Gravimetric soil moisture content of the site, determined two weeks prior to treatment, averaged 62-78% following several weeks with no rainfall. Just prior to treatment, the site received 98.9 mm of rainfall, and an additional 118.3 mm fell on the site during the treatment. This increased gravimetric soil moisture contents to 103-116%, by weight. These values represent very wet conditions that rendered the soil vulnerable to damage.

Mineral soil mounds originated through windthrow generally have a low soil bulk density and high porosity, thereby creating good growing sites in this hypermaritime climate. Compression of these mounds through trafficking up to four passes with the hoe-forwarding machine increased soil bulk density by 49 to 75%. However, the highest bulk densities measured were 1.2 g/cm^3, which is not considered excessively dense and would not be considered growth limiting (Minore et al. 1969, Heilman 1981).

4.2 TRACK DISTURBANCE SURVEYS

Several major disturbance classes or variations of these classes were observed (Table 1) following passage of the hoe-forwarding machine. Within the tracks, the average undisturbed areas amounted to 4%, 5% and 3% for the one-pass, two-pass and four-pass treatments, respectively. These undisturbed areas usually occurred either in or on the edge of depressional areas that had been protected by puncheon. The most common disturbance was compression of organic matter or decayed wood, the extent of which was similar for all three treatments. The extent of deep impressions was greatest in the one-pass treatment (30%)

Table 1. Disturbance levels of the tracked strips

Treatment	Disturbance classes (% track length, based on 25 point observations)								
	UN[1]	DWI(c)	OI(c)	MI(c)	OI(p)	MI(p)	OD(p)	MD	MOD
1-pass	4	14 d	30 d	9 d	1 d	1 d	3 d		1 d
		3 vd	11 vd	1 vd	5 vd		3 vd		1 vd
2-pass	5	9 d	22 d	5 d	5 d	1 d	5 d	1 d	1 d
		3 vd	19 vd	2 vd	3 vd		9 vd		
4-pass	3	5 d	17 d	7 d	5 d		1 d		
		3 vd	19 vd	2 vd	5 vd		13 vd		1 vd

[1] ***Disturbance class abbreviations:***
First letter(s): UN – undisturbed, intact forest floor, DW – decayed wood, O – organic matter, M – mineral soil, MO – mixed mineral soil and organic matter
Second (third) letter: I – impression, D – deposit, G – gouge
Lower case (in brackets): (c) – compression by equipment, by tracks, (p) – impression or deposit caused by puncheon
Disturbance class depths: s – shallow = <5 cm, d – deep = 5-25 cm, vd – very deep = >25 cm

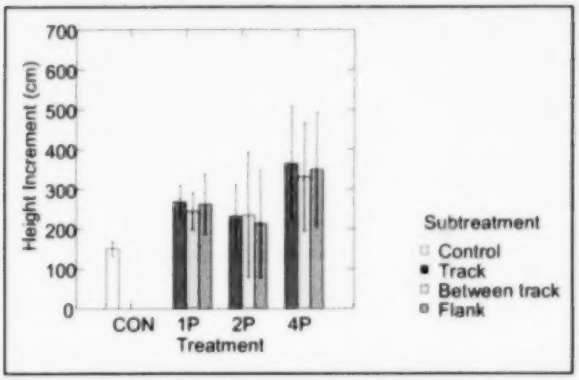

Figure 1. Nine-year height increment (Blocks 1 and 3 only). (Error bars represent standard error of the mean.)

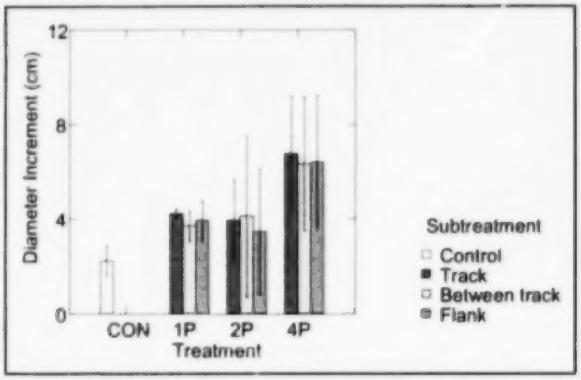

Figure 2. Nine-year diameter increment (Blocks 1 and 3 only). (Error bars represent standard error of the mean.)

but very deep impressions were more common in the two- and four-pass treatments (Plate 2). Deep compression of the mineral soil was most common in the one-pass treatment (9%). Very deep compression was similar (1-2%) for all treatments. The percentage of puncheon impressions into the organic matter was similar for all treatments. Puncheon impressions into the mineral soil were rare; this was likely due to the thick forest floor on the site and the use of adequate puncheon by the operator. Puncheon deposits seemed to increase with the number of passes, especially the very deep deposits. This was likely due to the machine operator using more puncheon material when more passes were planned. The breakage of this material with increased number of passes made it more difficult to remove. Mineral deposits and mixed organic and mineral deposits were of minor occurrence.

4.3 SEEDLING SURVIVAL

The average survival across the treatments at year five ranged from 79 to 82%; by year nine, additional mortality of 4 to 12% had occurred. The main cause of mortality in year one was the conifer seedling weevil (*Steremnius carinatus*), which caused damage to the lower stem, predominantly in Block 2, and to a lesser extent, planting in tracked depressions with a periodically saturated rooting zone. Additional mortality by year five was caused mainly by root disease (*Armillaria ostoyae*) with some additional damage by Roosevelt elk (*Cervus canadensis roosevelti*). The incidence of both these agents in year five appeared higher on the four-pass treatments. The cause of mortality by year nine was less apparent, although the shedding of chlorotic foliage on a number of the remaining trees indicates that root disease may still be affecting tree performance.

4.4 HEIGHT AND DIAMETER INCREMENTS

Significant differences in tree height and diameter increments were found between blocks after five growing seasons, confirming the need for a "blocked" experimental design. After five years, treatment impacts on Block 2 appeared to be somewhat negative. Tree height and diameter increments were higher on the control than on the treated areas of Block 2, where there was little competing vegetation. The historical windthrow disturbance of Block 2 (circa early 1900's) likely resulted in a greater availability of nutrients on this block, a denser stand and less understory vegetation. By contrast, results for Blocks 1 and 3, where salal cover was abundant, showed greater tree performance where the site had been disturbed.

Differences between blocks were even more apparent after nine growing seasons. By year nine, tree growth on the control of Block 2 was greater than on any of the other treatments. This resulted in large variability in the control treatments, which masked treatment differences across the three blocks. Two distinct regeneration phases had become obvious after nine growing seasons. Blocks 1 and 3 appeared to be transitional towards the CH phase with substantial salal in the understory; Block 2 appeared to be more typical of the HA phase with minimal salal cover, and a greater percentage of deerfern (*Blechnum spicant*), salmonberry, and fireweed (*Epilobium angustifolium*) in the understory. Treatment impacts were therefore determined separately for Blocks 1 and 3, independent of Block 2. Differences between treatments could not be statistically analysed in Block 2 due to insufficient sample size.

After nine growing seasons, the disturbance from the four-pass treatment on Blocks 1 and 3 appeared to have a positive effect on both seedling height and diameter growth, regardless of where the seedling had been planted with respect to the track (Figures 1 and 2). The beneficial effect from this greater disturbance appears to be due to a reduction in salal competition on this treatment. Salal cover on these two blocks was least abundant on the four-pass treatments after nine growing seasons.

Although differences could not be statistically analysed, the trees on the control of Block 2 had greater height and diameter growth than those on any of the other treatments, while growth response of trees across the other three treatments of Block 2 was similar. The lack of understory competition on this block likely provided the opportunity for the impacts of hoe-forwarding on both the soil physical and chemical properties to be more clearly expressed.

Seedling condition after nine growing seasons was best on Block 2 where most of the trees were rated either class 1 or 2 (see condition classes). By contrast, the majority of trees growing on Blocks 1 and 3 were rated as either class 2 or 3. Trees rated as

Table 2. Levels of foliar nutrients showing significant contrasts.

Treatment	Contrast	N	P	Mg	S	Zn	Mn	Al	SO_4-S
		% dry matter basis				ppm, dry matter basis			
Control		0.77	0.19	0.07	0.11	7.0	1040.4	273.0	297.0
1-pass	Track	**0.66 ***	**0.15 ***	**0.06 ***	**0.09 ***	**5.1 ***	977.7	**364.8 ***	**242.7 ***
	Between-track	**0.67 ***	**0.16 ***	**0.06 ***	**0.09 ***	**5.3 ***	1079.3	**365.4 ***	**247.1 ***
	Flank	0.74	**0.16 ***	**0.06 ***	**0.09 ***	6.3	1271.4	**351.4 ***	**222.3 ***
2-pass	Track	0.71	**0.17 ***	**0.06 ***	**0.09 ***	**5.8 ***	**1348.9 ***	325.8	254.4
	Between-track	**0.69 ***	**0.17 ***	**0.06 ***	**0.09 ***	**5.8 ***	**1344.4 ***	293.9	**187.8 ***
	Flank	0.74	0.17	0.06	**0.09 ***	6.9	**1334.0 ***	331.2	**235.2 ***
4-pass	Track	0.73	**0.15 ***	**0.05 ***	**0.09 ***	6.6	**1351.6 ***	320.3	235.2
	Between-track	0.78	**0.16 ***	**0.05 ***	**0.10 ***	6.6	**1382.2 ***	329.1	275.6
	Flank	0.78	**0.17 ***	**0.06 ***	**0.10 ***	6.6	**1234.2 ***	327.2	245.0

** indicates significant difference to the control at alpha = 0.05*

class 4 (poor) were only found in Blocks 1 and 3. Tree condition appeared closely and negatively related to salal cover.

4.5 FIVE-YEAR FOLIAR NUTRIENT LEVELS

Five-year foliar data was pooled for all three blocks. Regardless of the number of passes with the hoe-forwarding machine, the highest levels of N and Mg were found in seedlings planted on the control and on the flank. This should perhaps be expected since the flank is essentially the edge of the adjacent undisturbed 'control' area, and received minimal disturbance, at least on one side.

Regardless of planting position in relation to the track, both the four-pass treatment and the control had similar levels of foliar N (Table 2). The higher mean foliar N levels in the control were due to greater uptake of nitrogen by the control trees in Block 2. Foliar P, Mg, and S levels were generally somewhat lower on all trafficked treatments.

Regardless of number of passes with the hoe-forwarding machine, critical values (Ballard and Carter 1986, Carter 1992) suggest that N on this site was very severely deficient, P was slightly deficient, Mg was moderately to severely deficient depending upon where the seedling was growing in relation to the track, and K was slightly to moderately deficient. Although S would not be considered deficient, an induced deficiency could occur if nitrogen fertilizer alone was applied to the site.

Deficiencies of N and P may be attributed to competition from salal. Prescott and Weetman (1994) found that salal is capable of strongly competing with seedlings for both available N and P, and may actually inhibit ectomycorrhizal fungi in western hemlock, which are important for nutrient uptake.

As with N and Mg, levels of foliar micronutrients tended to be better on the control and on the flanks, regardless of the number of passes. Foliar Zn and SO_4-S levels were similar on the four-pass treatment and the control, but the one and two-pass treatments appeared to negatively affect uptake of these nutrients. The inconsistency of response to trafficking suggests uncertainty about the significance of these differences. Regardless of planting position in relation to the track, Mn uptake appeared to be enhanced by the two and four-pass treatments; and Al level was highest on the one-pass treatment. Both of these micronutrients can be toxic at these higher levels, and may lead to restricted uptake of other nutrients.

5.0 CONCLUSIONS

It was speculated at the beginning of this study that seedling performance might be reduced with increasing intensity of treatment. This may have been the result on Block 2 where after nine years, tree growth on the control appeared to be somewhat greater than on those trees growing on the trafficked areas. The 1906 windthrow event on Block 2 seems to have contributed to reduced regrowth of salal; thereby allowing soil impacts to be more clearly expressed.

However, on the remaining blocks where salal is abundant, we found that effects due to trafficking (especially four passes with the hoe-forwarding machine) were favourable for tree height and diameter growth, and for uptake of several nutrients after five growing seasons. The growth effects were even more apparent after nine growing seasons when salal cover had increased further.

It is obvious the thick forest floor and the use of puncheon on this site protected the soil/site from detrimental effects. However, higher levels of disturbance appeared to hamper the competing vegetation, salal in particular, allowing the trees to establish and more successfully compete for nutrients during the first nine years of growth. It is possible that on similar sites with thick forest floors and high salal competition, a reduction in the use of puncheon where fewer passes with the hoe-forwarding machine are required, may provide similar beneficial effects of disturbance. However, it is important to ensure that the level of disturbance does not reach the point where gains from reduced competition would be negated by adverse impacts on soil physical properties.

Other studies (Smith and Wass 1979) also suggest that a degree of disturbance may promote greater early seedling growth due to reduced competition. However, they suggest that negative effects such as reduced tree performance and site productivity may become apparent over the long-term. The appearance of

Armillaria ostoyae in the fifth growing season is perhaps suggestive of stress due to detrimental soil effects. The highest losses from this root rot did occur on the four-pass treatment. However, by year nine, the rate of mortality was reduced, and tree growth and performance was greatest where disturbance levels were highest. This site will continue to be monitored over the long-term to determine if impacts on tree performance become more apparent over time.

In this study, the soil disturbance results were obtained only for tracked areas of the treatments, i.e., by concentrating on the most disturbed areas. This is not comparable to the current procedure under the Forest Practices Code where point samples are taken for the standards unit as a whole so that untracked (and undisturbed) point samples would tally more frequently. Thompson's (1997) results showed that of the eight hoe-forwarding sites that were surveyed based on Forest Practices Code procedures, all were in compliance with the 5% disturbance limit.

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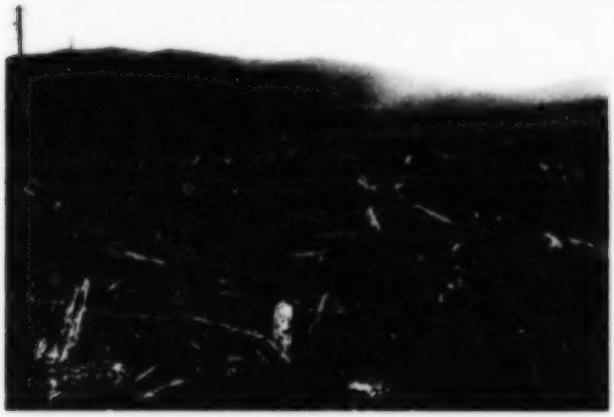

Plate 3. Four-pass treatment of Block 3 immediately post-treatment (1991).

Plate 4. Four-pass treatment of Block 3 after three growing seasons (1994).

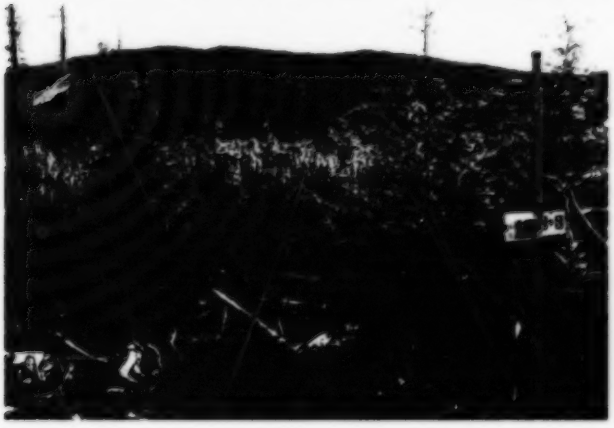

Plate 5. Four-pass treatment of Block 3 after five growing seasons (1996). (Photo courtesy of Alex Inselberg Photography.)

Plate 6. Four-pass treatment of Block 3 after nine growing seasons (2000).